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Electronic Supplementary Material

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Title: **A Framework for Evaluating Biodiversity Mitigation Metrics**

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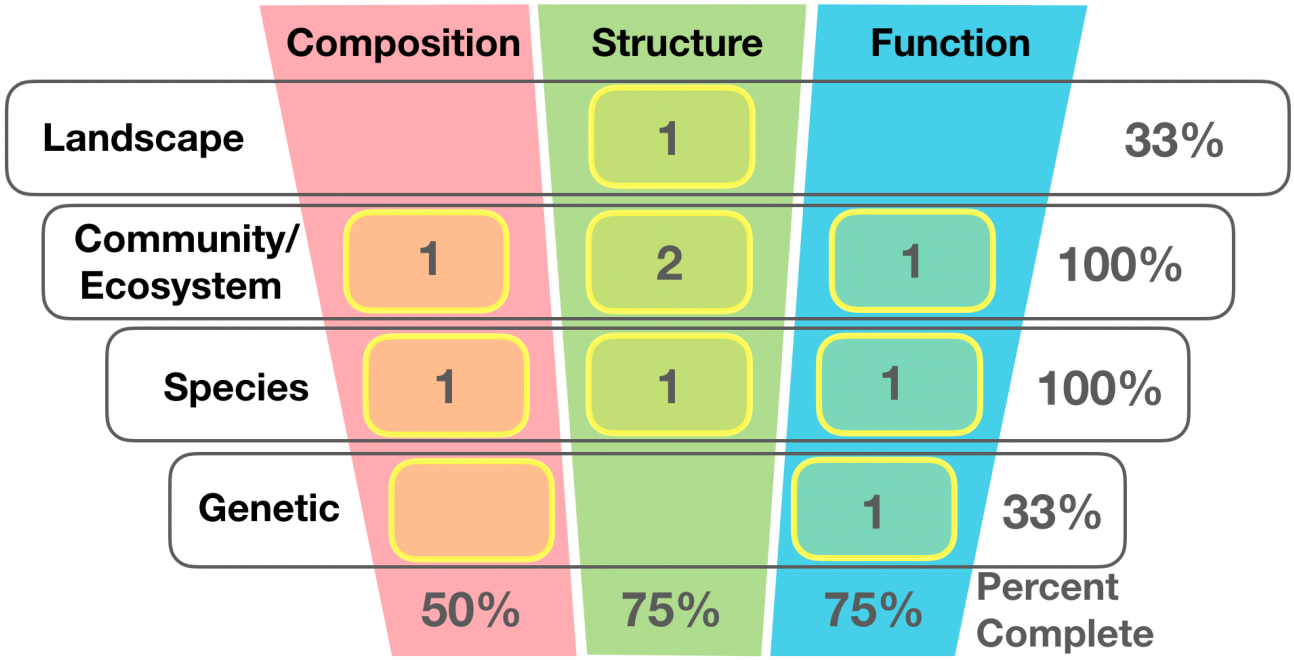
Appendix S1: Biodiversity Framework Example, Utah Prairie Dog

In the following appendix, we provide an example of a completed Biodiversity Framework with both the Biodiversity Scorecard (Scorecard) and Definitions & Descriptions (D&Ds). While the information in these forms is based upon real policy and implementation documents, the intent is to provide the reader (policy creators or other scientific researchers) with an examples of these documents that have been completed as if in a report. To do so, we utilized a real world example species, the Utah Prairie Dog (*Cynomys parvidens*), but this example is not intended to be a complete evaluation of the mitigation policy that has been implemented. The Scorecard and D&D were completed used based upon policy prescribed by the US Fish & Wildlife Service Final Revised Recovery Plan (2012) and habitat evaluation metrics described in the Utah Prairie Dog Habitat Credits Exchange Program Worksheets (2014). Both of these documents are freely available on the internet, but we have provided versions of these documents annotated for this research project at (location removed to preserve anonymity). The annotations describe elements of the Framework highlighted below and may be a valuable reference in understanding the following appendix. However, considering the length of the recovery plan (169 pages) and that these works are not created by the authors (excepting the annotations), they are omitted from this appendix document. As previously stated, while we provide an example of a completed Framework, we stress that (a) this is meant to be an example only and does not represent a true evaluation of the policy, programs, or effectiveness of Utah Prairie Dog management, and (b) it is not a comprehensively researched example.

We recommend that policy documents (recovery plans, etc.) as well as reports reviewing recovery efforts utilize the ordering and format as provided below. Blank examples of the Scorecard and D&D forms appear on the repository GitHub site already cited in this document. The Scorecard itself appears first in this example and serves as a visual index for the accompanying D&D forms. However, the the Scorecard itself is a summary of the D&D forms which should, therefore, be created first based on annotated reports (as we have done here). By maintaining consistency with this format in any applications, we hope to establish a system of easy reference both within a report and in comparing different mitigation plans.

Biodiversity Scorecard for:
Utah Prairie Dog Habitat Credits Exchange Program



Interpreting the Biodiversity Scorecard for the Utah Prairie Dog Habitat Credits Exchange Program ("Utah PD HabEx"): Yellow highlighted cells indicate biodiversity elements identified by peer-reviewed literature as particularly of conservation value to the focal species (Utah prairie dog). Numbers within the cells identify the number of metrics employed that are actually applied as part of the management plan (in this case the habitat exchange). Summary cells (rightmost column and bottommost row) identify the number of elements of biodiversity (cells) which are addressed by metrics in applied management.

The Utah PD HabEx is a fairly comprehensive program for biodiversity offsetting. Metrics required by this program measure each of the three attributes of biodiversity (Composition, Structure, and Function) at more than one scale. However, published research on this system has identified low genetic diversity due to population bottleneck as particular concern for conservation yet the mitigation program requires no metric to assess this concern. This mismatch between conservation challenge and metrics is identified by the yellow box in the lower-left cell (Genetic-level Composition) lacking any number that would indicate a metric is required by the policy or program.

Authors' note: The above Biodiversity Scorecard is based upon the D&D forms in the following pages. As stated above, this Scorecard is an example only and does not reflect a comprehensive examination of the focal system, literature on this system, or the mitigation policy documents.

COMPOSITION LEVEL: LANDSCAPE

Identity, distribution, richness, and proportions of patch (habitat) types and multipatch landscape types; collective patterns of species distribution (richness, endemism)

A. THREATS OR IMPACTS:

1. No threats or impacts identified for this element by literature review or policy document.

B. METRIC(S) REQUIRED:

1. No metrics required by policy to address this element

Authors' note: The above D&D form describes the biodiversity element of landscape-level composition. In this case, the scientific literature has not identified particular aspects of this element of biodiversity that are critical for the focal species. In addition, there are no metrics described in the Habitat Credits Exchange Program worksheet does not utilize metrics to measure this. For contrast, see the following page which has defined metrics and foci.

COMPOSITION LEVEL: COMMUNITY/ ECOSYSTEM

Identity, relative abundance, frequency, richness, evenness, and diversity of species and guilds; proportions of endemic, exotic, threatened, and endangered species, dominance-diversity curves; life form proportions; C3-C4 plant ratios

A. THREATS OR IMPACTS:

1. Areas of Utah Prairie Dog habitat with low spent species richness are associated with less weight gain, lower juvenile to adult ratios, and lower prairie dog density (Crocker-Bedford and Spillett 1981; Ritchie and Chang 2001)

B. METRIC(S) REQUIRED:

1. Plant species richness: assess native plant species richness (grasses and forbs). Areas with greater than 10 species (at least 3 grass and 3 forb) are rated higher than those with fewer. No explicit survey method described for acquiring this information.

Authors' note: The above D&D form describes the biodiversity element of community/ ecosystem-level composition. Here, the policy document clearly identifies this element of biodiversity as relevant for measurement and management to conserve the focal species. In section A, the authors provide a brief summary describing the threats to the species. This section states what the threat is as well as what the impact of the threat may be on the focal system. Section B identifies the metrics required by policy to measure the impacts/threats listed in Section A.

COMPOSITION LEVEL: SPECIES

Absolute or relative abundance; frequency; importance or cover value; biomass; density

A. THREATS OR IMPACTS:

1. Utah prairie dog population size: viable populations are the primary goal of the mitigation practices as declines are reported range-wide (USFS 2015).
2. Sylvatic plague: High population density is identified as increasing risk of plague-related extirpations among Utah prairie dog colonies (Barnes 1993).

B. METRIC(S) REQUIRED:

1. Utah prairie dog abundance: annual population surveys are required both for impact and offset locations. Although the Utah Prairie Dog Final revised recovery plan (1991) defines survey methodology, it provides no scientific justification for any methods as being appropriate for survey of this species.
2. Utah prairie dog density: population density is not directly assessed as part of metrics and is not part of credit calculation. However, overall size of the colony is calculated as part of the mitigation program, so density could be easily be calculated given the metrics of abundance and colony size.

Authors' note: The above D&D form describes the biodiversity element of species-level composition. Here, the policy document identifies two foci for this element of biodiversity that are important to management of the focal species. The enumerated lists in sections A and B are repeated and relate (i.e., Threat 1 is addressed by Metric1). Colored circles added here to clarify this relationship but should not be employed in an actual application of the Scorecard

COMPOSITION LEVEL: GENETIC

Allelic diversity; presence of particular rare alleles, deleterious recessives, or karyotypic variants

A. THREATS OR IMPACTS:

1. Inbreeding among prairie dog populations of various species in the *Cynomys* genus is well-documented (Hoogland, 1992, Travis et.al., 1995, Johnson and Collinge, 2004). Frequent plague-induced population crashes are exacerbating inbreeding and genetic diversity issues for this species, which may lead to high risk of extirpation (Travis et al., 1997). This is particularly of note among Utah prairie dogs which experienced a bottleneck event in the 1920's. Given the high risk of inbreeding depression and loss of genetic diversity due to plague and habitat fragmentation which, in turn may lead to long-term non-viability for the species, assessing gene flow in and around impacted areas is likely critical to viability. However, no study indicates a minimum population size for maintaining genetic variability in this species.

B. METRIC(S) REQUIRED:

1. No direct measure of genetic variability is conducted. Utah prairie dog genetic variability: population size surveys are required and higher conservation value is placed upon larger colony populations. This metric is used as a proxy for genetic diversity. Here, population size below 30 are not considered to have adequate genetic variability.

Authors' note: The above D&D form describes the biodiversity element of genetic level composition. Here, the policy document clearly identifies this element of biodiversity as relevant for measurement and management to conserve the focal species. However, the habitat credit exchange (the applied management document) does not address this. A metric of minimum population size is suggested as addressing this element in the applied management document, but no peer-reviewed scientific literature is cited supporting this claim in either the recovery plan or the applied management document.

STRUCTURE LEVEL: LANDSCAPE

Heterogeneity; connectivity; spatial linkage; patchiness; porosity; contrast; grain size; fragmentation; configuration; juxtaposition; patch size; frequency distribution; perimeter-area ratio; pattern of habitat layer distribution

A. THREATS OR IMPACTS:

1. Connectivity of suitable habitat ares within the greater ecosystem is linked to genetic diversity (C1) metric through Recovery Plan, but not through literature. Genetic diversity's value to prairie dogs identified in: Chauser, 1984 and Ritchie and Brown 2005,

B. METRIC(S) REQUIRED:

1. Utah prairie dog habitat connectivity: assessment of connectivity of each prairie dog colony via survey and aerial imagery interpretation. Sides of a prairie dog colony that are "barred from dispersal." If zero to two sides are barred from dispersal within 2km, colony receives a strong positive value in scoring. If three sides are barred, colony receives a small positive value. Barred on all four sides receives no positive value in scoring.

STRUCTURE LEVEL: COMMUNITY/ ECOSYSTEM

Substrate and soil variables; slope and aspect; vegetation biomass and physiognomy; foliage density and layering; horizontal patchiness canopy opens and gap proportions; abundance, density, and distribution of key physical features (e.g., cliffs, outcrops, sinks) and structural elements (snags, down logs); water and resource (e.g., mast) availability; snow cover

A. THREATS OR IMPACTS:

1. Utah prairie dogs preferably inhabit landscapes with lower densities of shrubs. (Collier 1875, Player and Urness 1982).

B. METRIC(S) REQUIRED:

1. Shrub canopy cover: Percent shrub canopy is assessed into three categories (above 20%, between 11 and 20%, and below 10%). These are considered low, medium, and high quality (respectively) value as prairie dog habitat.
2. Percent ground cover: Percent ground cover of plants is assessed into three categories (20% or less, 20-60%, and above 60%). These are considered low, medium, and high quality (respectively) value as prairie dog habitat). *Note: no justification for this metric is provided within the policy document to employ this metric.*

STRUCTURE LEVEL: SPECIES

Dispersion (microdistribution); range (macrodistribution); population structure (sex ratio, age ratio); habitat variables (see Community/Ecosystem Structure description); within-individual morphological variability

A. THREATS OR IMPACTS:

1. Population survival depends upon ability for prairie dogs to build good burrow systems. This requires well-drained soils to a depth of at least 1m (Collier 1975; Player and Urness 1982).

B. METRIC(S) REQUIRED:

1. No metrics are required by the policy to address this threat to the focal system.

STRUCTURE LEVEL: GENETIC

Census and effective population size; heterozygosity; chromosomal or phenotypic polymorphism; generation overlap; heritability

A. THREATS OR IMPACTS:

1. No threats or impacts identified for this element by literature review or policy document.

B. METRIC(S) REQUIRED:

1. No metrics required by policy to address this element

FUNCTION LEVEL: LANDSCAPE

Disturbance processes (areal extent, frequency or return interval, rotation period, predictability, intensity, severity, seasonality); nutrient cycling rates; energy flow; patch persistence and turnover rates; rates of erosion and geomorphic and hydrologic processes; human land-use trends.

A. THREATS OR IMPACTS:

1. No threats or impacts identified for this element by literature review or policy document.

B. METRIC(S) REQUIRED:

1. No metrics required by policy to address this element

FUNCTION

LEVEL: COMMUNITY/ ECOSYSTEM

Biomass and resource productivity; herbivory, parasitism, and predation rates; colonization and local extinction rates; patch dynamics (fine-scale disturbance processes), nutrient cycling rates; human intrusion rates and intensities.

A. THREATS OR IMPACTS:

1. No threats or impacts identified for this element by literature review or policy document.

B. METRIC(S) REQUIRED:

1. No metrics required by policy to address this element

FUNCTION LEVEL: SPECIES

Demographic processes (fertility, recruitment rate, survivorship, mortality); metapopulation dynamical population genetics; population fluctuations; physiology; life history; phenology; acclimation adaptation

A. THREATS OR IMPACTS:

1. Long-term persistence of colonies given plague risks is critical to species survival and known age of colonies may be a strong indicator or residence to plague. Persistent colonies may have lower population density overall with a wide dispersal of colonies (Cully 1993).

B. METRIC(S) REQUIRED:

1. Utah prairie dog colony persistence: persistence of colony over a duration of years is evaluated. Colonies known to be consistently populated for more than 10 years are given the highest value in calculation of credits. Those of intermediate age (between 6 and 10 years) are given an intermediate credit value, and those of unknown age or with occupancy less than 6 of the last 10 years receive no additional value in credit calculations.

FUNCTION

LEVEL: GENETIC

Inbreeding depression; outbreeding rate; rate of genetic drift; gene flow; mutation rate; selection intensity

A. THREATS OR IMPACTS:

1. Inbreeding among prairie dog populations of various species in the *Cynomys* genus is well-documented (Hoogland, 1992, Travis et.al., 1995, Johnson and Collinge, 2004). Frequent plague-induced population crashes are exacerbating inbreeding and genetic diversity issues for this species, which may lead to high risk of extirpation (Travis et al., 1997). This is particularly of note among Utah prairie dogs which experienced a bottleneck event in the 1920's. Given the high risk of inbreeding depression and loss of genetic diversity due to plague and habitat fragmentation which, in turn may lead to long-term non-viability for the species, assessing gene flow in and around impacted areas is likely critical to viability.

B. METRIC(S) EMPLOYED:

1. Population size surveys are required and higher conservation value is placed upon larger colony populations. This metric is used as a proxy for genetic diversity. No study supports minimum population size for maintaining genetic variability in this species. Here, population size below 30 are not considered to have adequate genetic variability, although no direct measure of genetic diversity/inbreeding is conducted